BE IT KNOWN that I, Hartmut **KRUEGER**, citizen of Germany, whose post office address and residency is at Am Eichenwaeldchen 17, 77830 Buehlertal, Germany; have invented certain new and useful improvements in a

METHOD AND APPARATUS FOR SUPPLYING CURRENT TO AN ELECTRONICALLY COMMUTATABLE ELECTRIC MOTOR

of which the following is a complete specification thereof:

BACKGROUND OF THE INVENTION

The invention is based on a method and apparatus for supplying current to an electronically commutated electric motor by a semiconductor power end stage, as disclosed in DE 29 30 863 A. This reference describes a method for load current determination in a direct current converter. A circuit for performing the method includes a bridge circuit connected to a voltage source. The load current is determined from currents flowing through the bridge branches. An electronic controller switches the phase currents of the motor accordingly. For this purpose a current detection device is arranged in each bridge branch.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a simpler and more economical method and an associated circuit means for controlling the phase currents of an electronically commutated electric motor, preferably of a three-phase electric machine.

This object and others, which will be made more apparent hereinafter, are attained in a method for supplying current to an electronically commutated electric motor, especially a three-phase direct current motor, by a semiconductor power end stage, with means for measuring the current delivered to the motor and with an electronic controller for branch currents of the motor.

In the method according to the invention only one current sensor is provided in the intervening circuit, i.e. the semiconductor end stage, in a common

conductor for the semiconductor switches of the semiconductor power end stage and the electronic controller is supplied with a signal from the current sensor, the terminal voltages of the individual circuit branches and the total voltage applied to the power end stage. The respective conducting state D.C. resistances of the semiconductor switches and/or the branch currents are determined from these signals and voltages by the electronic controller under logical inclusion of control signals produced by the electronic controller.

Preferably the semiconductor power end stage comprises MOSFET semiconductor switches, whose drain-source branches operate as current sensors. Because of this feature of the invention additional current sensors can be eliminated. A reduction of electrical losses, for example at a shunt, results as well as a construction cost savings. Also information regarding the conduction resistances in the individual semiconductor switches of the bridge branches of the power end stage is obtained.

It has proven advantageous to use a microcomputer as electronic controller for controlling the current supply, which for this purpose ascertains the voltage drops at the respective semiconductor switches from the difference of the total voltage applied to the power end stage and the corresponding the terminal voltages. Alternatively all six drain-source voltages can also be directed detected. The rotary position signals of a rotor position transmitter are preferably also supplied to the electronic controller for producing the control signals for the semiconductor switches. The semiconductor power end stage preferably is a semiconductor bridge circuit in the form of a so-called B6-converter bridge circuit,

in which the terminal voltages of the branch windings are read off or measured at corresponding connection points of respective connected pairs of the semiconductor switches and fed to the electronic controller. An especially simple structure results for the circuit apparatus according to the invention using readily accessible control signals.

In a preferred embodiment a determination of the respective conducting state D.C. resistances of the semiconductor switches occurs at a definite time point within the respective clock cycles in such a way that transients occurring when the semiconductor switches have been turned on have decayed. Thus the measurement results are not incorrect or faulty because of transient resistances shortly after control. Similarly a reconstruction of the branch currents can be performed with the help of the measured conducting state D.C. resistances and the measured currents.

The method according to the invention and the given circuit arrangement according to the invention is appropriate for a three-phase electronically commutated direct current motor (BLDC motor) with windings that are Y-connected, in which the individual motor branches are connected to the respective connections of the semiconductor switches of B6-converter bridge circuit. The method according to the invention is however not limited to this type of motor, but is suitable for other motors, for example for switched reluctance motors, asynchronous or synchronous machines and for traversal flow motors. Moreover other converter types can be used, for example the so-called H-bridge with separate bridge branches for each motor branch.

Additional features and advantageous embodiments of the invention are described in the dependent claims appended below and in the description of the examples of the invention.

BRIEF DESCRIPTION OF THE DRAWING

The objects, features and advantages of the invention will now be described in more detail with the aid of the following description of the preferred embodiments, with reference to the accompanying figures in which:

Figure 1 is a schematic diagram of a circuit arrangement according to the invention for supplying current to an electronically commutated electric motor;

Figure 2 is a graphical illustration showing control signal envelope curves with 120° block currents supplied to the three-phase electric motor;

Figure 3a is graphical illustration showing control signal envelope curves for 180° sinusoidal currents supplied to the three-phase electric motor; and

Figure 3b is graphical illustration showing the behavior of branch currents with a 180° sinusoidal current supply.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Main Circuit Structure

Figure 1 illustrates the principle circuit for current supply of an electronically commutated electric motor 10 by means of a semiconductor power end stage. The electric motor 10 comprises a stator 12 and a rotor 14. The winding branches of the stator 12 are designated 16, 18, 20 in Fig. 1. Branch currents I_1, I_2 and I_3 are supplied to the respective winding branches 16, 18 and 20.

The semiconductor power end stage for current supply of the electric motor 10 comprises MOSFET transistors T_1-T_6, which are connected in a half-bridge circuit (B6-converter bridge circuit). The drain-source voltages of the transistor power switches T_1-T_6 are designed U_{DS1}-U_{DS6}. The switches T_1, T_3 and T_5 are connected on their drain side with the plus pole of a direct current source. The source terminals of the switches T_2, T_4 and T_6 are connected to the minus pole of a direct current source with the voltage U. Further the source terminals of the switches T_1, T_3 and T_5 are connected, on the one hand, with the drain electrodes of the T_2, T_4 and T_6 and, on the other hand, with the terminals of the winding branches 16,18,20, whose other terminals are connected in a Y-connection.

A microcomputer (controller) 22 provides means for controlling the MOSFET switches T_1-T_6 and thus for controlling the current supplied to the

electric motor 10 and also for amplifying control signals. The signal of a single current sensor 24 is supplied to the microcomputer 22. The current sensor 24 is arranged in the common conductor 26 between the plus pole of the direct current source and the drain terminals of the transistors T_1, T_3 and T_5. The microcomputer 22 receives, as additional input signals, the terminal voltages U_1, U_2 and U_3 of the individual motor branches, which correspond to the source voltages of the switches T_1, T_3 and T_5 and the drain voltages of the switches T_2, T_4 and T_6 respectively. Furthermore the microcomputer (controller) 22 is connected with an output of a rotor position transmitter 28. On the output side the microcomputer (controller) 22 supplies control signals G_1 to G_6 to the MOSFET switches T_1-T_6.

Main Circuit Operation

After switching the circuit on, the D.C. voltage U is applied to the input terminal of the power end stage with the MOSFET switches T_1-T_6 and to the microcomputer (controller) 22. The switches T_1-T_6 receive the input signals according to the enclosed curves shown in Figs. 2 and 3a. These switches T_1-T_6 are switched to their conductive states for producing the branch currents I_1 -I_3 through the winding branches 16, 18, 20 according to these input signals. The control signals according to Fig. 2 are a matter of block control signals with respective currents over 120°, so that the current curves correspond to the control signal curves in the ideal case. The transistors T_1, T_3 and T_5 are continuously conducting during the respective supplied current blocks, the

magnitudes of the currents I_1, I_2 and I_3 are attained by clocking the MOSFET switches T_2, T_4 and T_6. Sinusoidal currents I_1, I_2 and I_3 with a half-wave duration of 180° are produced with a current supply according to Figs. 3a and 3b. Herein the input side MOSFET switches T_1, T_3 and T_5 and the output side switches T_2, T_4 and T_6 are switches pulsed for producing the sinusoidal current supply.

The microcomputer (controller) 22 receives a signal produced by current sensor 24 corresponding to the total input current I_{ges} of the power end stage, the terminal voltages U_1, U_2 and U_3 and a signal from the rotor position transmitter 28 providing information regarding the rotation position of the permanent magnet rotor 14, as input signals. The microcomputer (controller) 22 produces control signals G_1 - G_6 for the MOSFET switches T_1 - T_6 from these input signals according to the predetermined supply current behavior.

In the B6-converter bridge circuit in the embodiment illustrated with 6 MOSFET switches T_1 - T_6 and a three-phase electronically commutated D.C. motor with a start connection and with permanent magnet excitation (BLDC motor) the voltage U applied to the bridge as well as the respective voltage drops at the output side MOSFET switches T_2, T_4 and T_6, which correspond to the terminal voltages of the individual winding branches 16, 18, 20, are measured as input signals for the microcomputer 22. The drain-source voltages U_{DS} of the transistors T_1 - T_6 are determined by the microcomputer (controller) 22. This results in the following relationships: $U_{DS1} = U - U_1$; $U_{DS3} = U - U_2$; $U_{DS5} = U - U_3$; $U_{DS2} = U_1$; $U_{DS4} = U_2$; $U_{DS6} = U_3$.

Moreover the total current signal I_{ges} at the input of the current end stage is measured. The logical control signals G_1 - G_6 for the switches T_1-T_6 for control of the phase curves are derived from it. The control signals G_1 - G_6 are formed in the microcomputer (controller) 22 and are available without more effort.

In order to perform the method according to the invention which of the switches T_1 - T_6 is conducting and which is blocked is first determined and the allocation occurs, in which transistor exactly the measured current flows, which means which switch is controlled with the gate controlling signal "1". The switches T_1 - T_6 conduct via their inverse diodes also in free-running, however in that case the voltage drop is negative and it is under a definite bounding value.

Control signals G_1 - G_6 are formed in the microcomputer (controller) 22 with the help of signals from the rotor position transmitter 28 and are available. The total current I_{ges} flows in one of the switches T_1 - T_6, when it is the switch conducting the sole current of the three input side switches T_1 T_3, T_5 or the three output side switches T_2, T_4, T_6. Additional current sensors besides the sensor 24 are not needed in the method according to the invention since the MOSFET switches T_1 - T_6 themselves can be called upon as current sensors. The property of the power end stage that at least one MOSFET switch conducts the measured total current I_{ges} in the current supplying state can be used to determine the resistance of the drain-source branch R_{DS} in these MOSFET switches. When one of the switches T_1 - T_6 conducts the total current I_{ges}, its conducting state D.C. resistance is given by $R_{DS} = U_{DS}/ I_{ges}$. Thus the conducting state D.C. resistance is obtained for each MOSFET switch T_1 - T_6 for the respective

conducting of the total current I_{ges} within one electrical cycle of the motor 10. Temperature-dependent changes of the conducting state D.C. resistance is detected by frequent updating of the measured value. In order to minimize other interfering influences the measured values can be made more accurate by linear or non-linear filtering, for example by low-pass filtering. At the time at which the branch current is not identical with the measured current I_{ges} the branch current can be determined by the relationship $I_{1-3} = U_{DS}/ R_{DS}$ with the help of the measured drain-source voltage of the corresponding MOSFET and the corresponding value for R_{DS} of the branch current.

It has proven advantageous when the measurement and evaluation of the necessary variables take place at definite time periods, especially so that the measured values obtained shortly after the known switching times occur within one clock or pulse cycle. This guarantees that the transient switching process of the concerned MOSFET switch is decaying so that the transient resistance, which is active shortly after the controlling, does not influence the measurement result.

The measurement of the drain-source voltages U_{DS} of the MOSFET switches T_1 - T_6 preferably occurs by means of a voltage divider comprising a series circuit including an ohmic resistance and a capacitor, in which the voltage at the connection point between the components is fed to the microcomputer (controller) 22 via an amplifier and an analog-digital converter with an analysis circuit. The analog-digital converter is preferably part of the microcomputer.

A conventional pulse frequency for the control of the MOSFET switches

T_1 - T_6 is 20 kHz. In order to obtain exact measurement results during the determination of the voltage drop U_{DS} in the drain-source branch of the MOSFET switches T_1 - T_6 it is appropriate when the motor currents I_1 - I_3 are about 10 A or more. This sort of motor can be successfully used as a drive motor in a motor vehicle, in which features for reducing costs due to a large number of component parts, in the present case especially for reducing the number of current sensors, are especially important.

The disclosure in German Patent Application 102 47 900.3 of October 14, 2002 is incorporated here by reference. This German Patent Application describes the invention described hereinabove and claimed in the claims appended hereinbelow and provides the basis for a claim of priority for the instant invention under 35 U.S.C. 119.

While the invention has been illustrated and described as embodied in a method and apparatus for supplying current to an electronically commutable electric motor, it is not intended to be limited to the details shown, since various modifications and changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can, by applying current knowledge, readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention.

What is claimed is new and is set forth in the following appended claims.